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## A study of dispatcher's route choice model based on evolutionary game theory

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### Abstract

In this study, we developed a route choice model that considered travel time reliability and traffic impediments, including traffic accidents. Based on evolutionary game theory, we designed the model to identify a route that a dispatcher chooses when considering changes in daily route travel times and traffic impediments using measured data. Evolutionary game theory is a game theory formulated using dynamics, and it analyses the distribution and change of a combination of strategies. A model from Roth & Erev (1995), which was taken as a representative of models that assumed trial and error learning, was used.

Using the model designed for this study, we conducted two case studies. The first case study reduced the standard deviation of some routes to 3/4 of the original value, and the second case study reduced the charge of a toll road by half. As a result, the combination of route choice strategies changed significantly.

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*Keywords:* Freight transport; route choice model; evolutionary game theory; travel time reliability

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### 1. Introduction

With the development of just-in-time shipping, logistics companies cannot afford delays in shipping consignments to their destinations. Therefore, logistics companies plan the shipping time to include additional time, considering variability of average travel time due to traffic congestion and traffic

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accidents. Freight traffic requires strict correspondence for the variability of travel time compared to passenger traffic.

In previous studies, some models have analysed route choice behaviour for daily variability of travel time or unexpected events. However, few studies have modelled route choice behaviour considering both daily variability and unexpected events.

Therefore, in this study, we developed a route choice model that considered travel time reliability and traffic impediments, including traffic accidents. Based on evolutionary game theory, we designed the model to identify a route that a dispatcher chooses when considering changes in daily route travel times and traffic impediments using measured data. The data was collected from 579 delivery trucks from four logistics companies, through a probe investigation during one month.

## 2. Model

### 2.1. Outline of model

In a related model based on game theory, Bell (2004) modelled an action of risk aversion from traffic impediments, such as traffic accidents, as a game between a dispatcher and a devil that causes impediments on links.

The present study was based on the study of Bell (2004), and we applied evolutionary game theory and developed a model in which a dispatcher considers the influence of the variability of travel time on the route choice.

Generally, when and where an accident occurs is unknown. In other words, information necessary for a look-ahead method is not available. For this reason, we felt that the assumption of a look-ahead in game theory was too strong.

Without a look-ahead game theory, the evolutionary game theory assumes that increase or decrease of strategic share depends on whether a particular strategy succeeded or not. The model adapts well to represent a phenomenon by applying evolutionary game theory.

Many models exist within evolutionary game theory. In this study, the dispatcher was assumed to decide on a route choice considering past experience, and a model of trial and error learning was applied. If a player performs trial and error learning, a player only requires two things: choice of actions and criteria to evaluate the results of actions. A player does not need to know the perspective when a player makes a certain choice and does not need to know other player's strategy. Furthermore, a player does not need to know the other player's results of action and gain. Trial and error learning is a versatile algorithm that can be applied without this information.

A model of Roth & Erev (1995) given as a representative of a model that assumed trial and error learning was applied. A player updates their tendency of choice at time  $t+1$ , adding reinforcement that is given as a result of choice at time  $t$  to the tendency at time  $t$ . As a result of the game, the player's choice is converted into a certain share.

1. Setting of players:  
Based on Bell's study, the players are a dispatcher and a devil that causes traffic impediments.  
Player 1: A dispatcher (A freight carrier)  
Player 2: A devil that causes traffic impediments (traffic accidents)
2. Strategy of players:  
Player 1 was assumed to choose a minimum-generalized-cost route and player 2 was assumed to cause a traffic impediment on a single link.

Strategy of player 1: choose a route with minimum costs among  $N$  routes

Strategy of player 2: cause a traffic impediment on a single link among  $M$  links

### 3. Model flow:

Strategy share of player 1 is determined by the following steps.

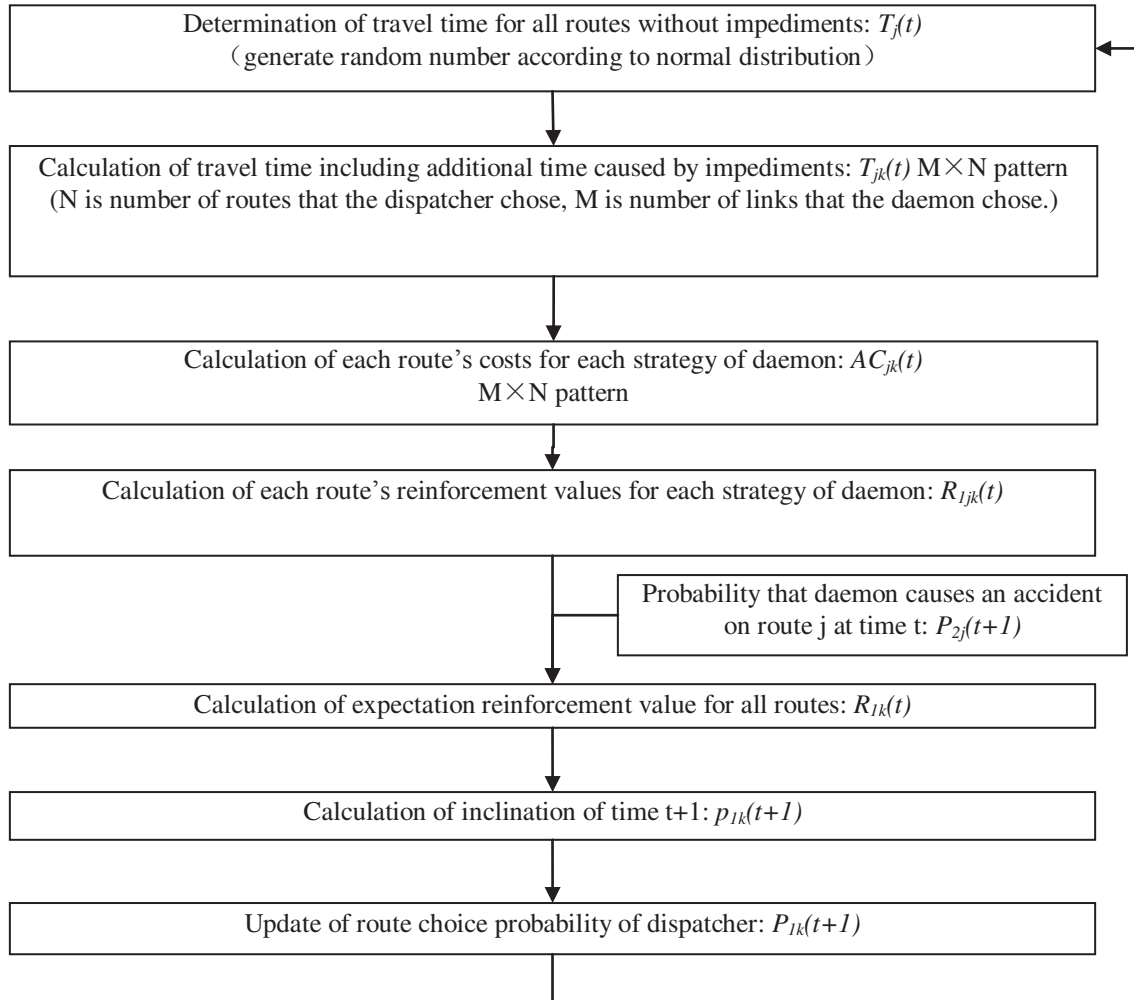


Fig. 1. Model flow

In the following sections, the calculations for each step shown in the Model flow are defined.

### 4. Determination of the travel time for all routes without impediments:

Travel time of route  $j$  at time  $t$  is calculated by the average travel time and standard deviation of the route. The travel time is calculated by the box Muller method and assigned stochastically on the assumption that the distribution of travel time follows a normal distribution.

$$T_j(t) = \sqrt{\sigma_j} \sqrt{2 \log(u_1) \cos(2\pi(u_2)) + \mu_j} \quad (1)$$

where,  $T_j(t)$ : Travel time of route  $j$ , at time  $t$   
 $u_1, u_2$ : Uniform random numbers  
 $\sigma_j$ : Standard deviation of travel time of route  $j$   
 $\mu_j$ : Average travel time of route  $j$

The average travel time of each route and standard deviation of travel time are calculated by the following equations. Additionally, the average travel time of each road section and the standard deviation of travel time are given by the probe investigation data.

The average travel time of route  $j$  is

$$\mu_j = \sum_i^n \mu_i \quad (2)$$

The standard deviation of the travel times of route  $j$  is

$$\sigma_j = \sqrt{\sum_i^n \sigma_i^2 + 2 \sum_{i=1}^{n-1} \sum_{l=i+1}^n \text{COV}(X_i, X_l)} \quad (3)$$

where,  $\mu_i$ : Average travel time of road section  $i$   
 $\sigma_i$ : Standard deviation of road section  $i$   
 $\text{COV}(X_i, X_l)$ : Covariance of the travel time of road sections  $i$  and  $l$

##### 5. Calculation of travel time including additional time caused by impediments:

Travel time including additional time caused by impediments is calculated for each strategy of the daemon. The travel time is calculated using the  $N \times M$  pattern, where  $N$  is the number of routes that the dispatcher choose and  $M$  is the number of links that the daemon chose for impediments.

$$T_{jk}(t) = T_j(t) + \sum_{k=1}^m (D_{jk} \times ET_{jk}) \quad (4)$$

where,  $T_{jk}(t)$ : Travel time of route  $j$  at time  $t$  where the daemon generates an impediment on link  $k$   
 $D_{jk}$ : Dummy variable (If link  $k$  is included in route  $j$  then  $D_{jk}=1$ ; if link  $k$  is not included in route  $j$  then  $D_{jk}=0$ )  
 $ET_k$ : Additional travel time when an impediment occurred on link  $k$

##### 6. Calculation of each route's costs for each strategy of daemon:

Each route's costs are calculated for each strategy of daemon. The  $N \times M$  pattern for travel time is calculated.

$$AC_{jk} = TC_{jk}(t) + RC_{jk}(t) + \alpha \times T_j(t) + \beta \times D_{jk} \quad (5)$$

where,  $TC_{jk}(t)$ ,  $RC_{jk}(t)$ ,  $T_j(t)$ ,  $D_{jk}$ : Travel-time cost, vehicle-operating cost, road toll, and dummy variable of route j at time t where the daemon causes an impediment on link k.

$\alpha, \beta$ : Parameters (parameters are determined based on situations of the actual route choice.)

#### 7. Calculation of each route's reinforcement values for each strategy of daemon:

Each route reinforcement value is calculated for each strategy of daemon. The N×M pattern for travel time is calculated.

$$\begin{aligned} R_{1jk}(t) &= 0; & r_{jk}(t) &= (TC_b + RC_b) - AC_{jk} < 0 \\ R_{1jk}(t) &= 1; & r_{jk}(t) &= (TC_b + RC_b) - AC_{jk} \geq 0 \end{aligned} \quad (6) \text{ and } (7)$$

where,  $r_{jk}(t)$ : Gain by choosing route j at time t where the daemon causes an impediment on link k

$TC_b, RC_b$ : Travel-time cost and vehicle-operating cost by base travel time

#### 8. Calculation of the expectation reinforcement value for all routes:

An expectation reinforcement value for each route is calculated by the weight of strategy probability of the daemon.

$$R_{1j}(t) = \sum_{k=1}^m (R_{1jk}(t) \times p_{2k}(t)) \quad (8)$$

where,  $p_{2k}(t)$ : Probability that the daemon causes an accident on link k.

#### 9. Calculation of inclination of time t+1:

The inclination at time t+1 is calculated by substituting an expectation reinforcement value in following equation. The reinforcement value of player 1, which is a component of the tendency to choose route j at time t+1, was assumed to be given by the gain at time t. The reinforcement value was determined as follows.

$$p_{1j}(t+1) = (1 - \phi) p_{1j}(t) + R_{1j}(t) \quad (9)$$

where,  $p_{1j}(t)$ : Tendency that player 1 adopts route j at time t

$R_{1j}(t)$ : Reinforcement given for  $p_{1j}(t)$  at time t

$\phi$ : A parameter to express the speed of the oblivion ( $0 < \phi < 1$ )

#### 10. Update of route choice probability of the dispatcher:

The probability of selecting route  $j$  is calculated by the inclination of each route.

$$P_{ij}(t+1) = p_{ij}(t+1) / \sum_j p_{ij}(t+1) \quad (10)$$

$$\sum_j P_{ij}(t+1) = 1 \quad (11)$$

#### 11. Probability of the impediments (strategies of daemon):

We assumed that impediments occur with a fixed probability on each link. The probability is based on the traffic accident rate available from statistics.

### 2.2. Iterative calculation

The reinforcement value, inclination, and route choice probability of time  $t$  are updated by a calculation result, and the same operations are iterated.

## 3. Application of model

For shipping scenarios from Toyota to Tahara and Toyota to Tobishima, and from 7 am to 10 am and 7 pm to 10 pm, four situations were applied to the model. The parameters  $\alpha$  and  $\beta$  of Equation (5) were changed, and their approximate model result for route choice share was calibrated to be the actual route choice share.

### 3.1. Routes

Six routes were selected for both Toyota-Tahara and Toyota-Tobishima shipping scenarios based on actual shipping routes.

#### 1. Toyota-Tahara

- Route 1: Highway route (Toyokawa-Bridge, Kosakai-Bypass)
- Route 2: Highway route (Toyokawa Bridge)
- Route 3: Highway route (Detours Toyokawa-Bridge)
- Route 4: Highway route (Detours Toyokawa-Bridge)
- Route 5: Highway route (Toyokawa-Bridge)
- Route 6: Motorway route

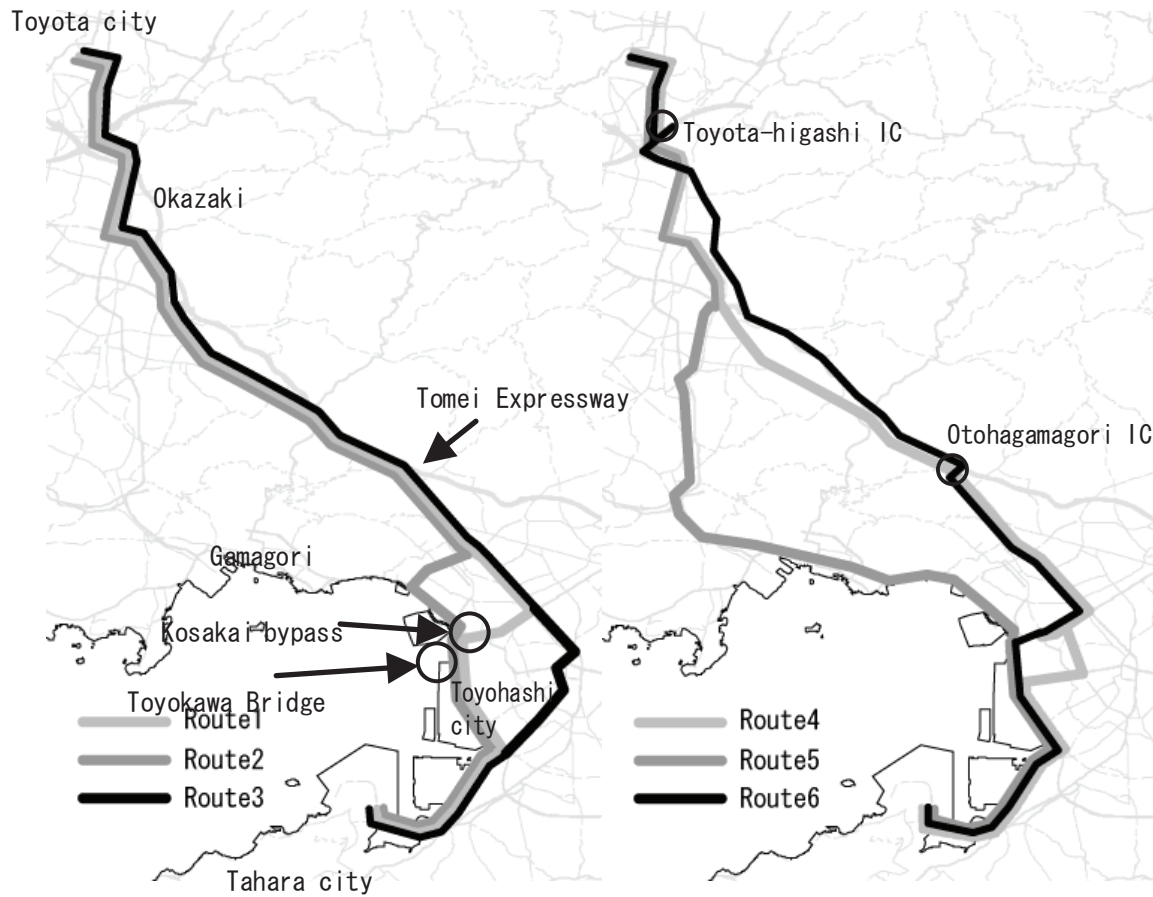


Fig. 2. Toyota-Tahara routes

## 2. Toyota-Tobishima

Route 1: Highway route

Route 2: Motorway route (Meiko-chuo IC –Tobishima IC) (Motorway travel is shortest)

Route 3: Motorway route (Toyota-minami IC –Tobishima IC) (Motorway travel is longest)

Route 4: Highway route

Route 5: Motorway route (Toyoake IC –Tobishima IC) (Motorway travel is second longest)

Route 6: Motorway route (Nagoya-minami IC –Tobishima IC) (Motorway travel is third longest)



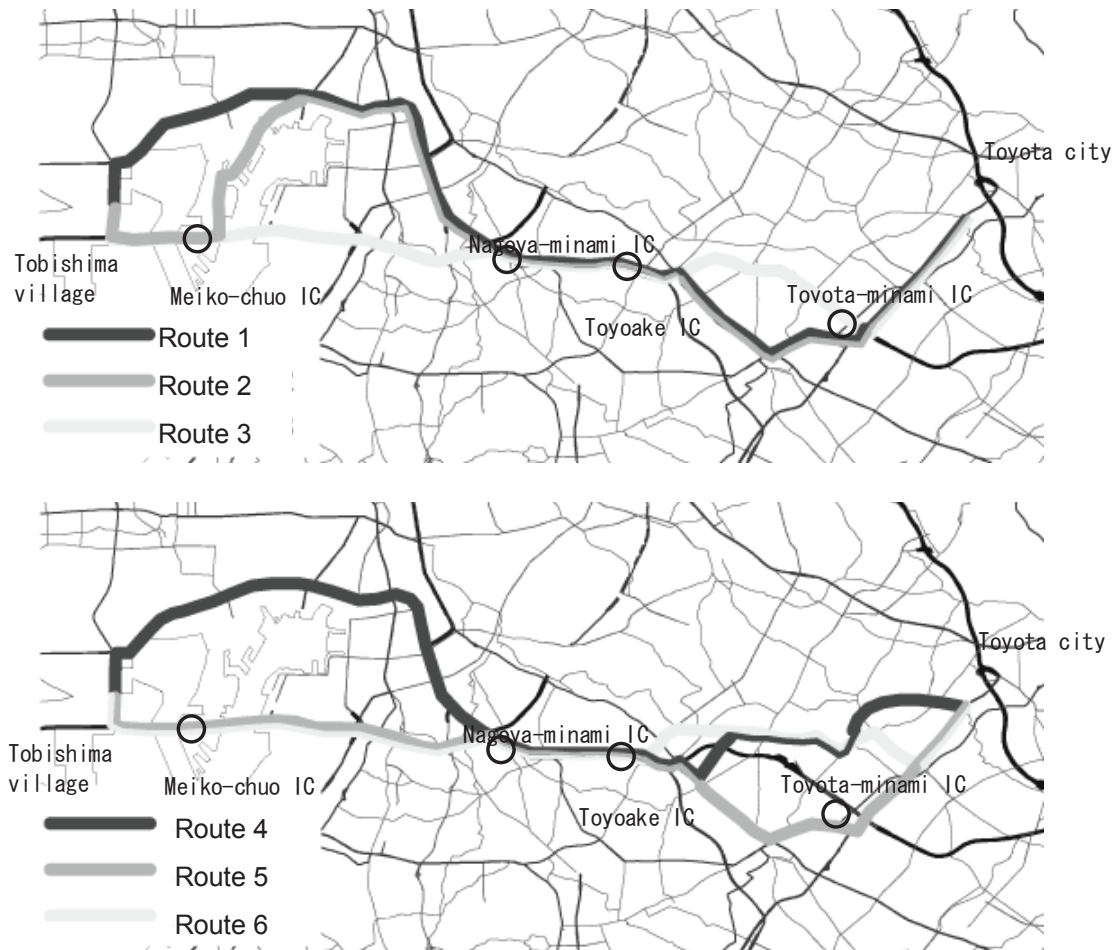


Fig. 3. Toyota-Tobishima routes

### 3.2. Travel time of routes

#### 1. Toyota-Tahara

The values for both average travel time and standard deviation are shortest on Route 6, which uses the motorway. The average travel time and the standard deviation of Route 1 are short. The differences between Routes 1 and 6 are great for the 7–10 am scenario, but are minimal for the 7–10 pm scenario. In addition, the standard deviation of the 7–10 pm scenario hardly exhibits a difference between each route.

Table 1. Average travel time and standard deviation (Toyota-Tahara)

	Distance (km)	Average travel time (minutes)	Standard deviation of travel time (minutes)
Route1	60.0	127.4	7.6
		106.0	5.4
Route2	60.5	132.7	8.8
		106.8	5.3
Route3	59.5	152.2	11.6
		121.4	5.4
Route4	64.8	132.8	7.7
		117.3	5.3
Route5	62.3	139.3	8.0
		115.6	5.5
Route6	62.9	101.8	7.2
		83.6	5.1

## 2. Toyota-Tobishima

For the 7–10 am scenario, the average travel time and standard deviation of Route 3 are shortest, and those of Route 2 are longest. Although the average travel time and standard deviation have similar trends at 7–10 pm, these are shorter than those of at 7–10 am.

Table 2. Average travel time and standard deviation (Toyota-Tobishima)

	Distance (km)	Average travel time (minutes)	Standard deviation of travel time (minutes)
Route1	37.2	76.2	5.6
		64.1	3.7
Route2	39.3	85.0	6.6
		72.3	5.1
Route3	31.7	41.4	3.2
		37.3	2.7
Route4	36.5	77.8	6.1
		62.2	4.0
Route5	32.3	53.1	4.5
		44.7	3.1
Route6	32.0	58.6	4.8
		50.5	4.5

### 3.3. Result of reproduction by model simulation

A route share estimated by model simulation was compared to an actual route share by changing the  $\alpha$  and  $\beta$  values. As a result, the model simulation exhibited results similar to the actual route choice except in the case of Toyota-Tahara for 7–10 pm.

*Toyota-Tahara, 7–10 am:*

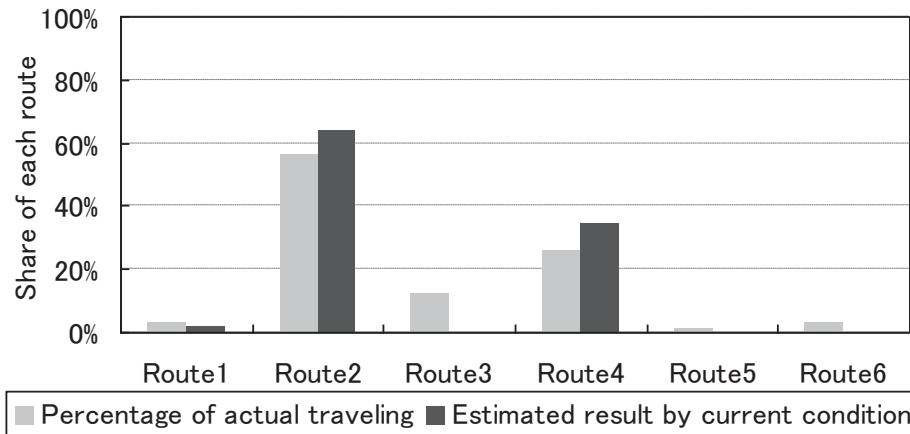


Fig. 4. Result of reproduction by model simulation (Toyota-Tahara 7–10 am)

*Toyota-Tahara, 7–10 pm:*

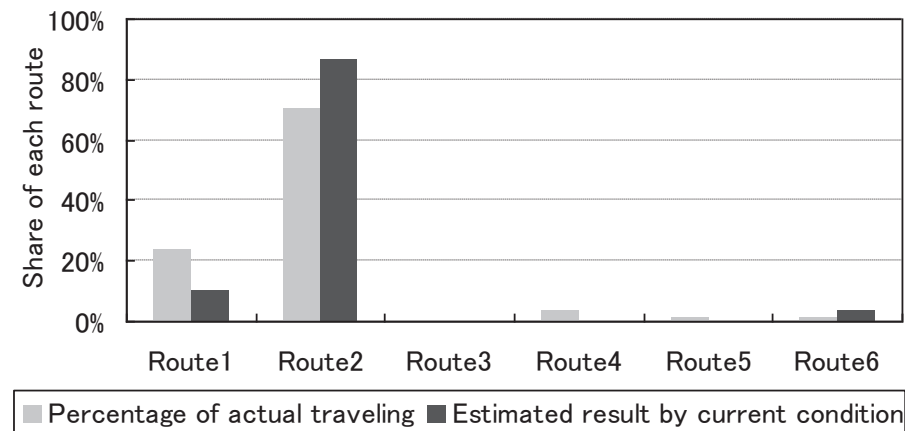


Fig. 5. Result of reproduction by model simulation (Toyota-Tahara 7–10 pm)

*Toyota-Tobishima, 7–10 am:*

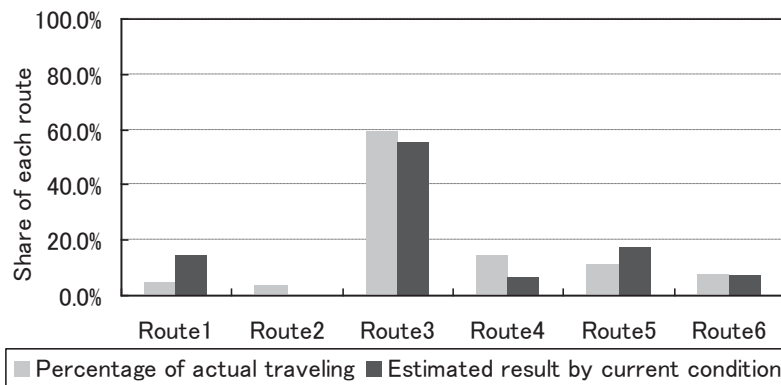


Fig. 6. Result of reproduction by model simulation (Toyota-Tobishima 7–10 am)

*Toyota-Tobishima, 7–10 pm:*

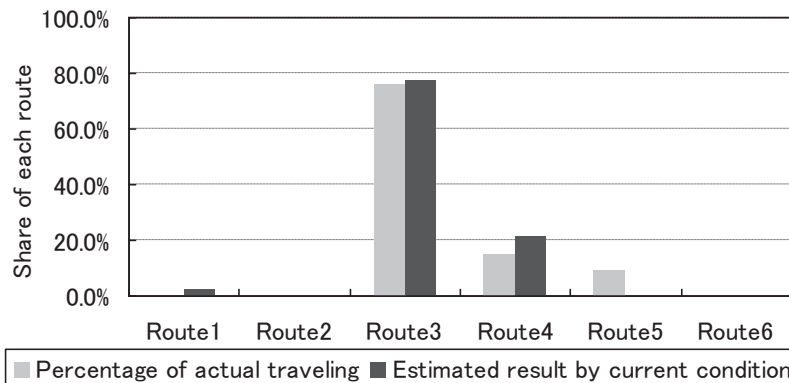


Fig. 7. Result of reproduction by model simulation (Toyota-Tobishima 7–10 pm)

## 4. Case study

### 4.1. Case

Two case studies were conducted; the standard deviation was reduced in the first case and the toll road charge was discounted in the second case. The influence on the route choice due to these changes was estimated.

#### *Toyota-Tahara, Case 1:*

For the route that did not use the Toyokawa-Bridge, the variability of travel time was assumed to decrease due to road improvements, and the influence on the route choice share was analysed. The case where the standard deviation is reduced to 3/4 of the original value was estimated for Routes 3 and 4.

#### *Toyota-Tahara, Case 2:*

This case reduced the toll road charge by half without changing the average travel time and the standard deviation. In this case, the reinforcement values of Routes 1 and 6, which use the toll road, were increased.

#### *Toyota-Tobishima, Case 1:*

For the route that uses National Highway No. 23, the variability of travel time was assumed to decrease due to road improvements, and the influence on the route choice share was analysed. The case where the standard deviation is reduced to 3/4 of the original value was estimated for Routes 1, 2, and 4.

#### *Toyota-Tobishima, Case 2:*

This case reduced the toll road charge by half without changing the average travel time and the standard deviation. In this case, the reinforcement values of Routes 2, 3, 5, and 6, which use the toll road, were increased.

### *4.2. The result of the estimation*

#### *Toyota-Tahara, 7–10 am:*

As a result of 1,000 iterations of Case 1, the choice share of Route 4 increased to 98% and that of Route 2 decreased to 2% because of the standard deviation reduction of Routes 3 and 4.

For Case 2, the choice share of Route 1 increased to 84% and that of Route 2 decreased to 10% because of the toll road charge being half-price. The reinforcement values of Routes 1 and 6 increased. Although the toll road charge was reduced, the share of Route 6 was 0%.

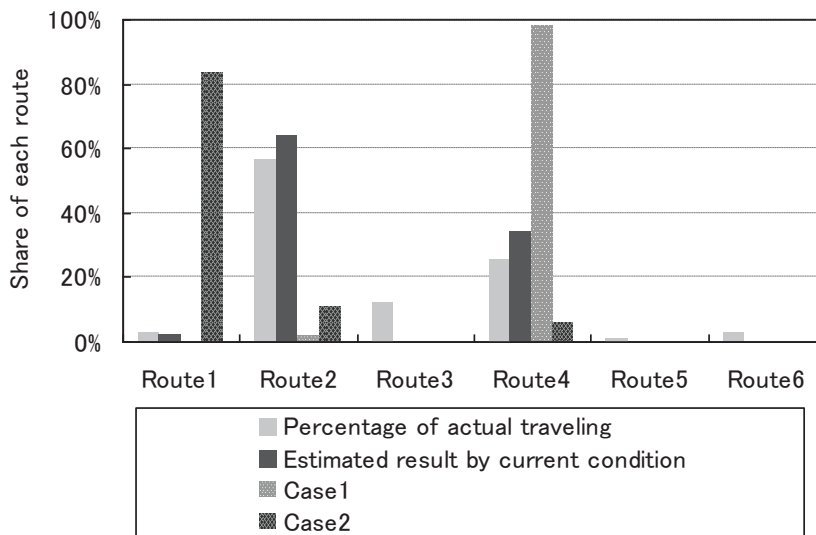


Fig. 8. Comparison with the estimation result (Toyota-Tahara, 7–10 am)

#### *Toyota-Tahara, 7–10 pm*

For Case 1, the route share did not change. Because the standard deviation of each route is shorter than the average travel time, shortening of the standard deviation did not have a major influence on the route choice. For Case 2, shares of Routes 1 and 2, which used a toll road, increased. However, the increase was not large.

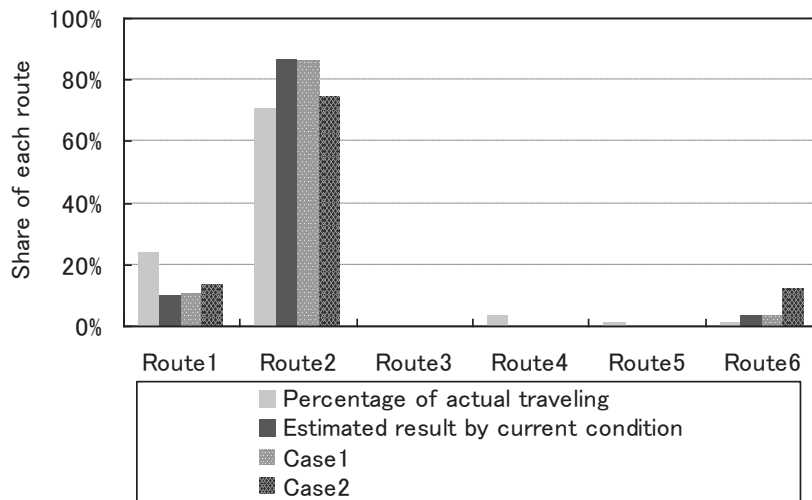


Fig. 9. Comparison with the estimation result (Toyota-Tahara, 7-10 pm)

#### Toyota-Tobishima, 7-10 am

In Case 1, for Routes 1, 2, and 4, which used National Highway No. 23, the share of Route 1 increased to more than 90%. However, Route 2 was still not selected as a route choice. This may be due to the considerably longer travel time of Route 2 compared to other routes. In Case 2, Route 3, which used the Isewangan Expressway for the longest distance, increased to more than 80%.

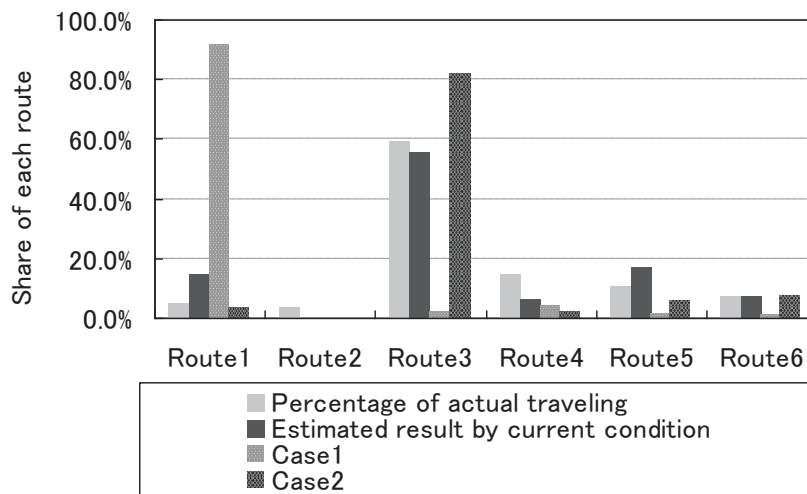


Fig. 10. Comparison with the estimation result (Toyota-Tobishima 7-10 am)

### *Toyota-Tobishima, 7–10 pm*

For Case 1, the route choice shares of Route 3 decreased, and the route choice shares of Routes 1 and 4 increased. Because Route 2 has a long average travel time, this route share was not selected even when the standard deviation was reduced.

For Case 2, the route shares of Routes 5 and 6, which use the Isewangan Expressway, increased. Because the toll road became half-price and the cost difference of Routes 3 and Routes 5 and 6 decreased, the share of Route 5 decreased slightly.

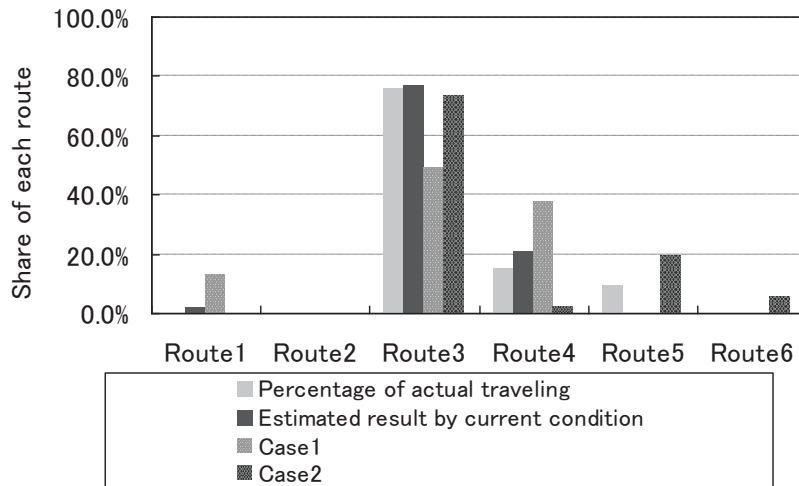


Fig. 11. Comparison with the estimation result (Toyota-Tobishima 7–10 pm)

## 5. Conclusion

In this study, we employed the evolutionary game theory to develop a model that assumed a strategy change based on whether the strategy succeeded, after selecting a certain strategy for the shipping of goods. This model was designed based on the actual route choice process that a dispatcher performs, including the consideration of additional time and selecting a route based on past experience. The change in route choice behaviour was analysed with real decision-making processes using this model.

Specifically, the road improvements having a greater influence on route choice behaviour can be found and the model can contribute to determining the road improvements that should take priority.

For the model development, we assumed the logistics company to consider gain as the difference of the sum of the time cost, the running cost, and the toll of the road. In addition, we assumed the gain to reinforce the next behaviour. We designed the model to consider the distribution of travel times and the probability of traffic accidents, and set the parameters of the gain structure in the model based on actual route choice behaviour obtained from probe investigation data. As a result, we could design the model such that the route choice share estimated by the model was similar to the actual route choice share.

Table 3. Result of estimated parameters

Situation of model applications	Parameter of generalized cost	
	Resistance value of road toll : $\alpha$	Resistance value of Toyokawa bridge passage : $\beta$
Toyota-Tahara / 7~10am	4.0	70
Toyota-Tahara / 7~10pm	1.0	70
Toyota-Tobishima / 7~10am	1.5	—
Toyota-Tobishima / 7~10pm	1.5	—

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